Multi-Band CRPA Solution HEDGE-8016

Global Navigation Satellite Systems (GNSS) have become an indispensable component of modern civilian and defense platforms spanning autonomous vehicles, unmanned aerial systems (UAS), maritime navigation, telecommunications, critical infrastructure timing, and precision-guided technologies. However, the increasing dependency on GNSS positioning, navigation, and timing (PNT) has made these systems a strategic target for intentional radio-frequency (RF) interference, including both jamming and spoofing.

As the RF threat landscape evolves toward multi-band, wideband, and multi-source attacks, where conventional single-band anti-jam solutions may not be sufficient to guarantee robust and continuous PNT availability.

Controlled Reception Pattern Antennas (CRPAs) combined with adaptive digital beamforming represent the most effective physical-layer defense against RF interference in contested GNSS environments. By exploiting spatial discrimination using multi-element antenna arrays, CRPA-based systems can form deep adaptive nulls in the direction of interferers while preserving the desired satellite signals. However, many existing CRPA solutions remain limited to a single GNSS frequency band, leaving other valuable bands unused.

This white paper introduces a **triple-band CRPA architecture** that delivers simultaneous anti-jamming protection across the **L1, L2, and L5 frequency bands**.

1. System Overview

The proposed **multi-band GNSS CRPA** architecture provides independent spatial interference mitigation across the **L1, L2, and L5** GNSS frequency bands while maintaining compatibility with external **multi-band GNSS** receivers. Independent band-specific CRPA processing is applied to the received signals, and the interference-mitigated **RF outputs** are combined into a unified **multi-band** signal for **GNSS positioning.**

By decoupling spatial anti-jam processing from the GNSS navigation receiver, the architecture enables flexible integration with professional-grade multi-band GNSS receivers. This provides a scalable solution for maintaining reliable multi-band GNSS positioning under complex and multi-source interference conditions.

The **HEDGE-8016-S130** weighs less than **720 g** with a **130 × 130 × 28 mm** envelope while the **HEDGE-8016-C200** weighs less than **1320 g** with a **⌀ 200 × 38 mm** envelop. A key architectural principle is the **strict separation of spatial interference mitigation per frequency band**. Each GNSS band is processed with fully independent RF paths, digitizers, and adaptive beamforming engines. This ensures that wideband, multi-source, or cross-band interference does not introduce algorithmic coupling or performance degradation between bands.

HEDGE-8016: 8+8 Multi-Band CRPA
(L1 + L5 / L1 + L2)
Optimized for high-order spatial nulling and dense interference environments.

- Up to 7 independent nulls on L1/L2 and L5 bands.
- Multi-Band Signal Reception:
    - GPS: L1C, L1C/A, L2C,L5
    - Galileo: E1 , E5a
    - BeiDou: B1C, B1I, B2a

HEDGE-8016: 8+4+4 Multi-Band CRPA
(L1 + L2 + L5)
Independent adaptive spatial processing on L1/L2/L5

- Up to 7 independent nulls (L1).
- Up to 3 independent nulls per band(L2 + L5).
- Multi-Band Signal Reception:
    - GPS: L1C, L1C/A, L2C,L5
    - Galileo: E1 , E5a
    - BeiDou: B1C, B1I, B2a

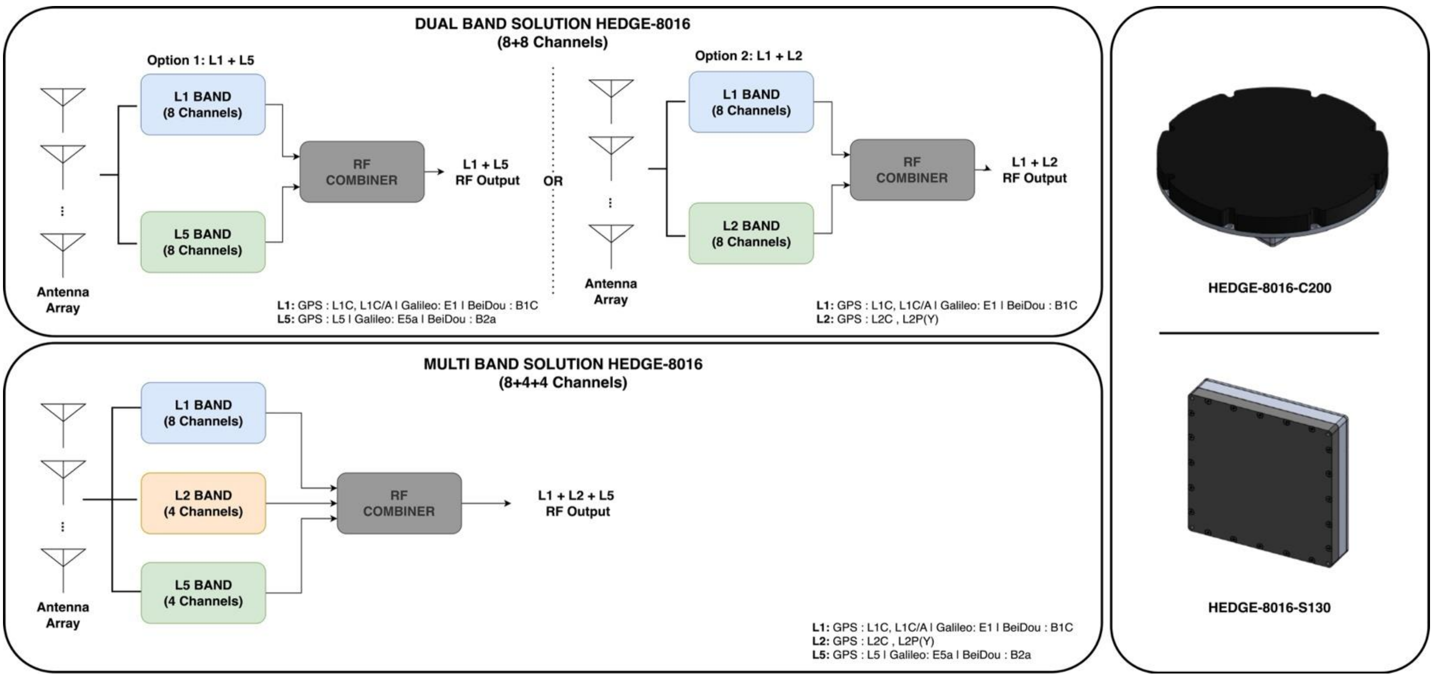

Figure 1. Multi-Band CRPA Solutions

2. Form Factor – Integration Envelope

One of the central design objectives of the proposed multi-band CRPA front-end is to deliver high-performance spatial interference mitigation within a **compact mechanical envelope** suitable for airborne, ground, and unmanned platforms where size, weight, and power (SWaP) constraints dominate system selection.

This physical footprint is significantly smaller than conventional multi-band CRPA systems, which often require physically separated antenna modules or bulky analog combining stages. By integrating all spatial processing and RF reconstruction hardware into a single enclosure, the system reduces platform-level wiring complexity and supports rapid mechanical integration.

This SWaP-focused design ensures that advanced multi-band CRPA protection can be deployed on platforms traditionally limited to single-band or low-performance anti-jam solutions, thereby expanding the operational envelope of GNSS-dependent systems operating in contested RF environments.

HEDGE-8016-C200 is designed to remain below:

- **Total mass:** < **1320 g**
- **Mechanical envelope:** < **Ø200× 38 mm**

HEDGE-8016-S130 is designed to remain below:

- **Total mass:** < **720 g**
- **Mechanical envelope:** < **130 x 130 x 28**

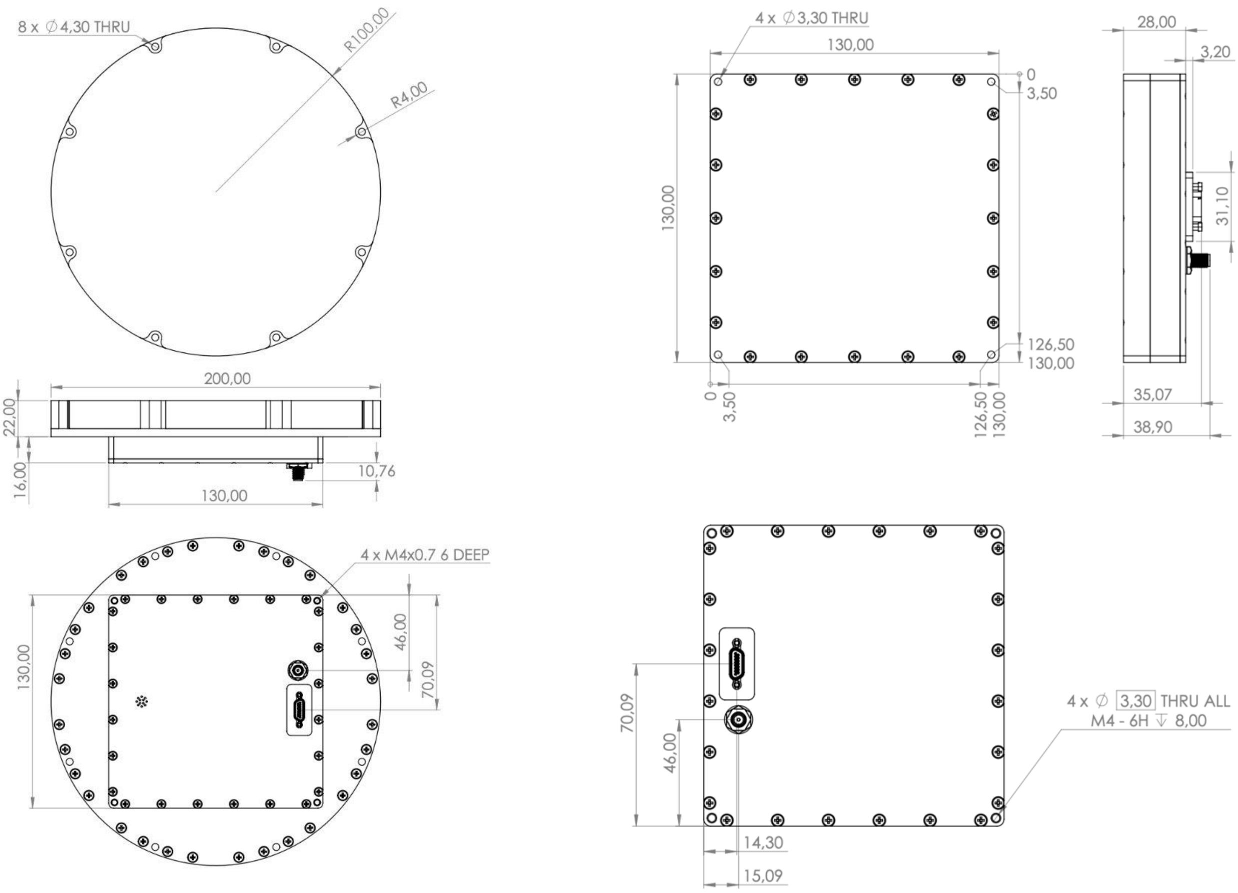

Figure 2. HEDGE-8016-C200/S130 Dimensions

3. Multi-Band Signal Reception and Modulation Fidelity

Modern GNSS constellations increasingly employ wideband signals in the L5 and L2 frequency bands to provide improved multipath resistance, ranging accuracy, and interference resilience. The proposed multi-band CRPA architecture is designed to receive and protect these signals through adaptive spatial filtering while preserving their intrinsic modulation characteristics and wideband structure.

The lower-band subsystem (HEDGE-8016) processes the following wideband signals:

- **GPS L2C, L2P(Y) (1227.6 MHz)**: 20-MHz bandwidth, BPSK-modulated
- **GPS L5 (1176.45 MHz)**: 10-MHz bandwidth, BPSK-modulated
- **Galileo E5a (1176.45 MHz)**: Total 20 MHz bandwidth – 10 MHz on each channel, BOC-modulated
- **BeiDou B2a (1176 MHz)**: Wideband BPSK/BOC signal

As shown in **Figure 3**, the L5 and L2 bands include multiple wideband GNSS signals from GPS, Galileo, BeiDou, QZSS, and NavIC. Across these signals, the RF and digital receive chains are designed to maintain low group-delay variation and high linearity, minimizing the distortion of the received waveform during reception and spatial filtering. Preserving signal fidelity is particularly important for receivers that exploit advanced GNSS processing techniques such as precise code and carrier-phase tracking, long coherent integration, and dual-frequency ionospheric correction.

This combination of **wideband multi-constellation reception, spatial interference mitigation, and signal-fidelity preservation** enables the CRPA architecture to support modern GNSS waveforms without compromising the characteristics required for high-accuracy positioning and robust signal processing.

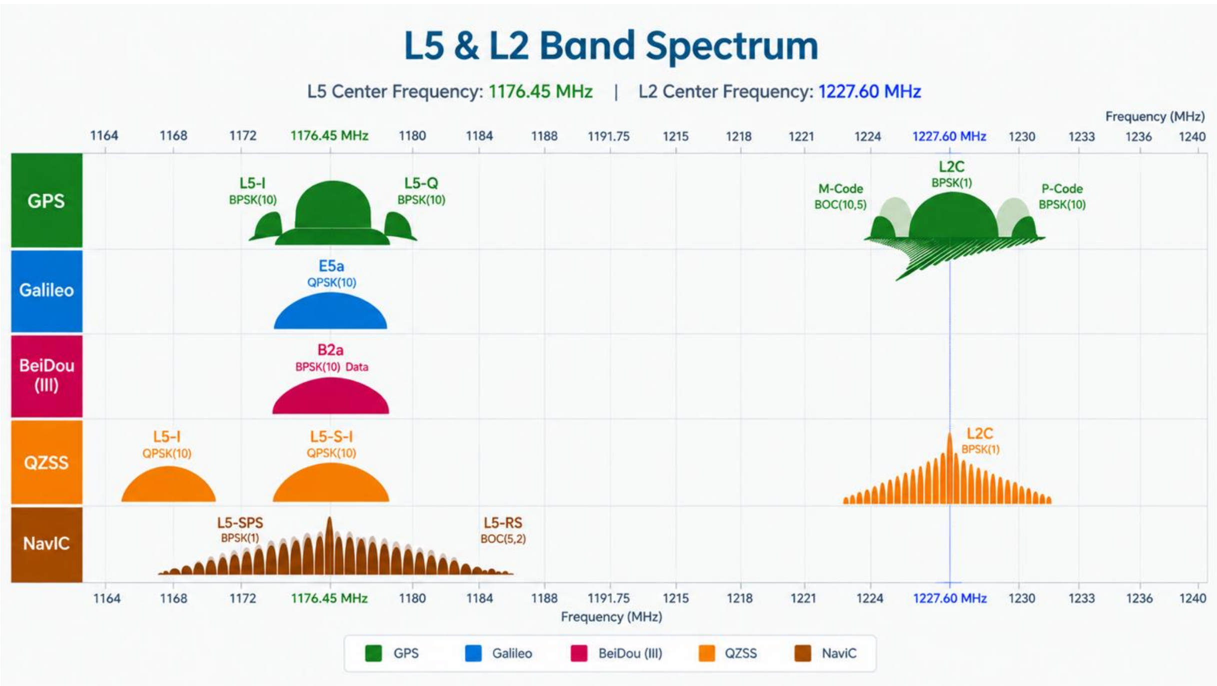

Figure 3. L5/L2 GNSS Signal Spectrum

4. Interference Test Setup and Conditions

The experimental evaluation setup, illustrating the simulated interference environment, is shown in **Figure 4 and Figure 5.**

The test setup is designed to evaluate the positioning performance of the **HEDGE-8016** under multi-directional interference conditions, while keeping the receiver and **CRPA** configuration fixed. During the experiments, the average received interference power at the Device Under Test (DUT) was maintained within −58±2 dBm to ensure consistent and repeatable test conditions. As illustrated in **Table 1**, received interference levels in this range are representative of the levels that may occur at the **DUT** depending on jammer distance and radiated power.

The evaluation further focuses on a band-dominant interference condition in which the **L1** signal is strongly suppressed. This edge-case scenario demonstrates the benefit of multi-band reception, where the **L5** band remains available to support continued positioning despite severe **L1-band** interference. The corresponding positioning results, are presented from **Section 6** onward.

Distance to Jammer (m)	Received Interference Level at DUT (dBm)	Equivalent J/S (dB)
30	≈ −20	110
110	≈ −30	100
340	≈ −40	90
1000	≈ −50	80
2500	≈ −60	70

Table 1. Illustrative Interference Level at the DUT Distance (50 W EIRP, Omni-Directional Jammer Antenna)

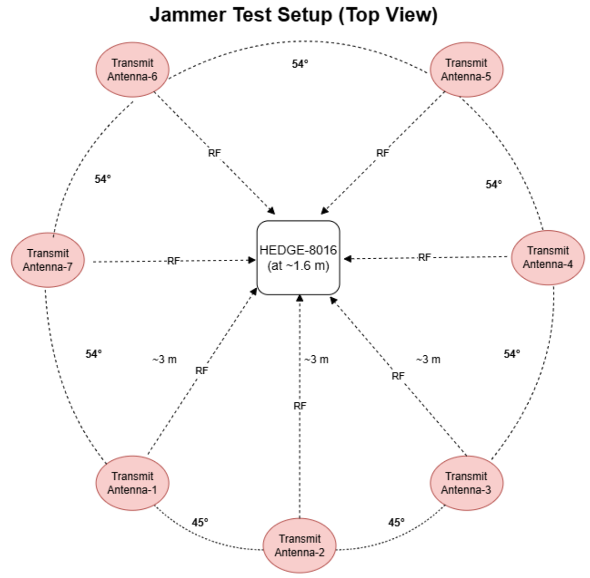

Figure 4. HEDGE-8016 and Jammer Setup Top View

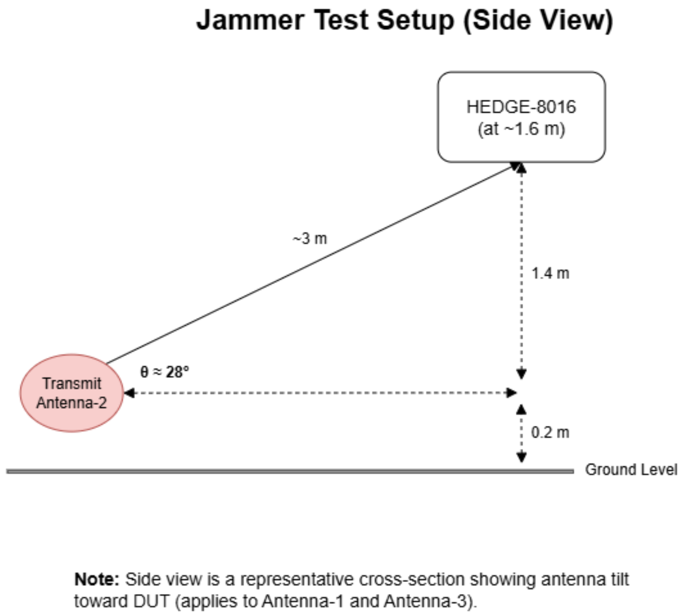

Figure 5. HEDGE-8016 and Jammer Setup Side View

5. Multi-Band GNSS Positioning Performance

The positioning performance of the **HEDGE-8016** was first evaluated under interference-free environment to establish a baseline for the subsequent jamming tests. The evaluation considers the available GNSS satellites, signal quality, and resulting positioning accuracy under **multi-band** operation. The **dual-band** positioning performance obtained under **no-jam** conditions is presented in **Figure 4.**

Figure 5 illustrates the positioning performance when interference is applied exclusively to the **L1** band at an average received interference level of **−50 dBm** using **seven interference** sources. The resulting **2D** and **3D** accuracy values provide an initial indication of the positioning impact under this severe interference condition. Detailed information on the jammer configuration and test conditions is provided in **Section 5**.

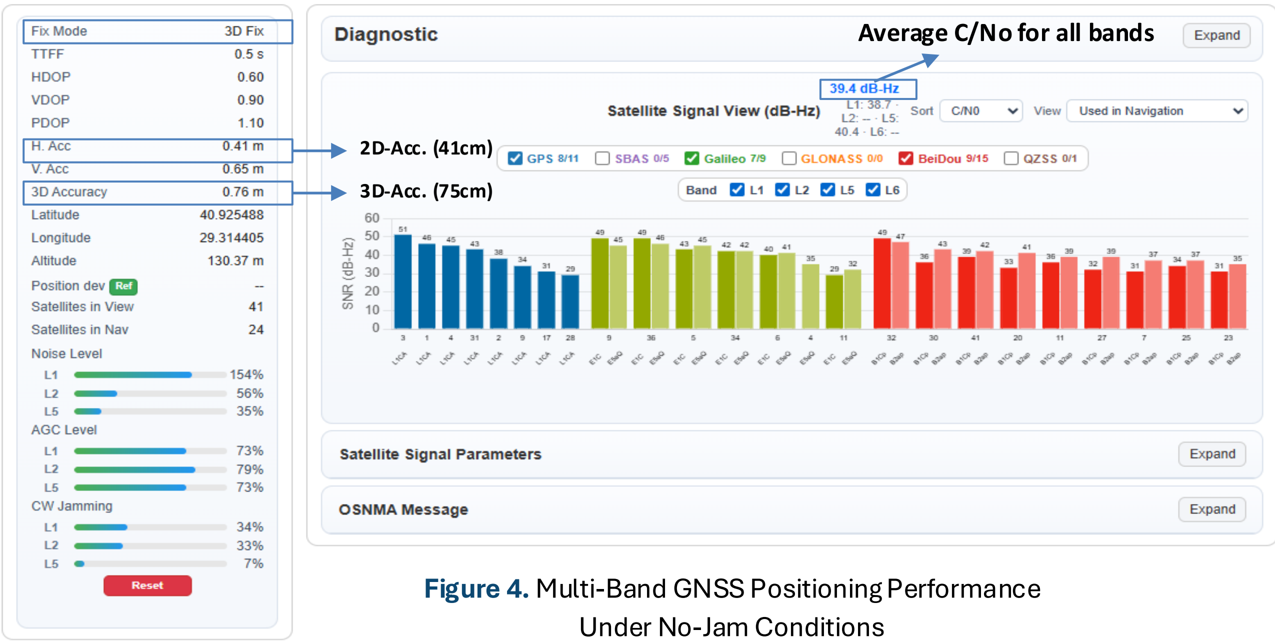

Figure 4. Multi-Band GNSS Positioning Performance Under No-Jam Conditions

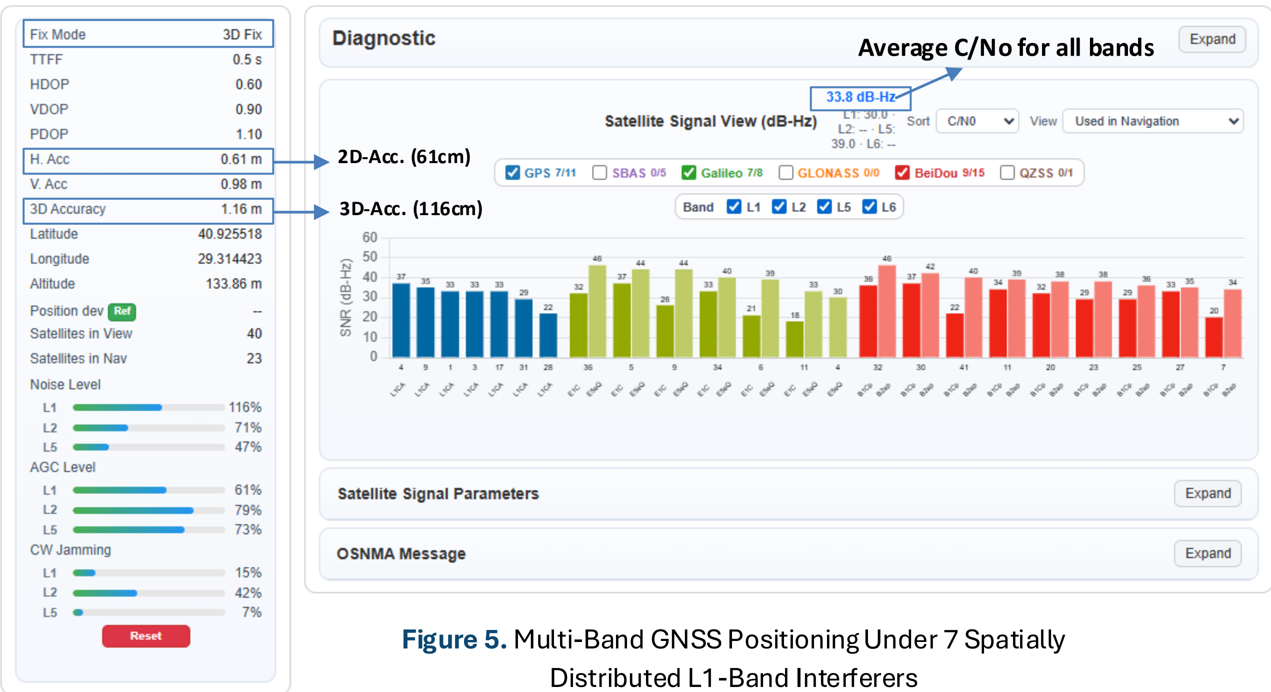

Figure 5. Multi-Band GNSS Positioning Under 7 Spatially Distributed L1-Band Interferers

7. Conclusion

The **multi-band CRPA** GNSS front-end architecture presented in this document provides a comprehensive and scalable solution for ensuring reliable satellite navigation in contested, dynamic, and high interference RF environments. The **HEDGE-8016** supports **flexible multi-band** configurations, including an **8+8** channel **L1/L5 or L1/L2** configuration and an **8+4+4** channel **L1/L2/L5** configuration. These configurations provide independent spatial interference mitigation across the selected GNSS frequency bands, enabling **robust multi-band** reception and **high-precision** positioning in high interference RF environments.

The architecture preserves the full spectral integrity of wideband safety-of-life signals such as **Galileo E5** and **Beidou B2**, while providing deep adaptive nulling against narrowband, wideband, and multi-source interferers. The resulting interference-clean RF outputs are recombined into a unified multi-band signal that can be consumed by any professional grade triple-band GNSS receiver without requiring modifications to its acquisition or tracking algorithms.

A defining advantage of the **HEDGE-8016 multi-band CRPA** architecture is its ability to maintain high accuracy navigation solution under severe band-specific interference. In particular, the experimental results demonstrate that **strong L1-band** interference does not necessarily result in loss of **high-precision** positioning when an additional GNSS band remains available.

Despite its advanced spatial processing capabilities, the system remains highly compact and lightweight, with a total mass **below <720 g** and an overall envelope of **130x130x28 mm.** This enables deployment on SWaP-constrained platforms, including UAVs, UGVs, and compact maritime assets.

By decoupling spatial anti-jam processing from the navigation engine itself, the proposed design provides long-term scalability, allowing future enhancements in beamforming algorithms, RF front-end design, or GNSS receiver technology without requiring structural changes to the system architecture. This modularity ensures compatibility with evolving GNSS constellations and emerging threat models while maintaining a stable integration interface.

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